FiMPART'15, Hyderabad, India

Crashworthiness Evaluation of Empty and Foam-Filled AZ31B Magnesium Beams under Three-Point Bending

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Presenter:

Mr. Marc Hampel

DLR

Outline

- Introduction
- Motivation
- Material testing and characterization
- Three-point bending: experiment
- Three-point bending: simulation
- Conclusion and future work

DLR overview

❑ DLR's mission

- exploration of the Earth and the solar system
- research aimed at protecting the environment
- development of environmentally-friendly technologies to promote mobility, communication and security.

7.700 employee are working at 32 research institutes and facilities in

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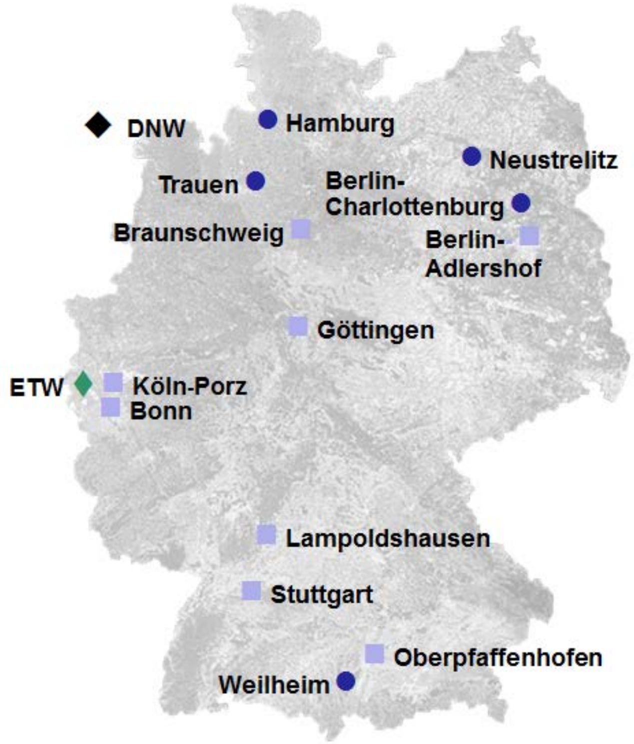
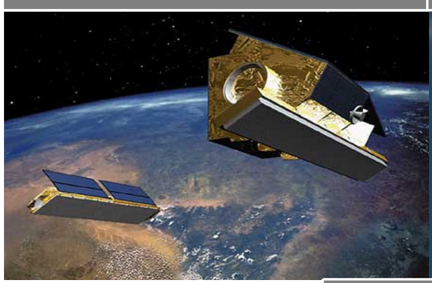
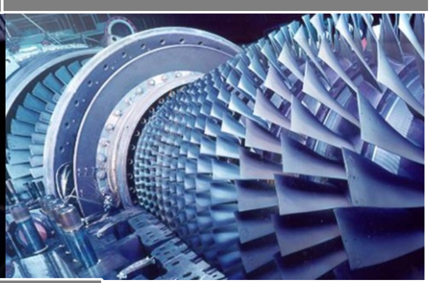


SPACE	AERONAUTICS	TRANSPORT	ENERGY
			

SECURITY

Institute of Vehicle Concepts - Overview

- **Institute director: *Prof. Dr.-Ing. Horst E. Friedrich***

- Orientation and research fields:
  - Road vehicle concepts
  - Rail vehicle concepts
  - Alternative power train
  - Lightweight vehicle construction

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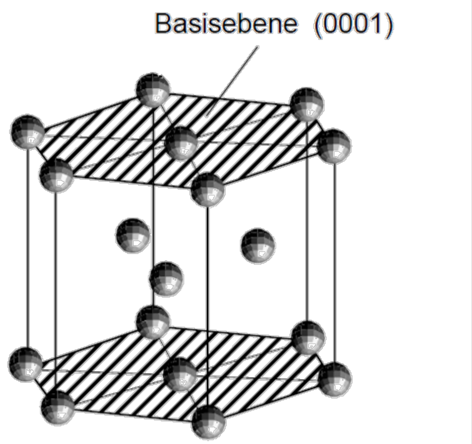
Introduction

Magnesium Alloys:

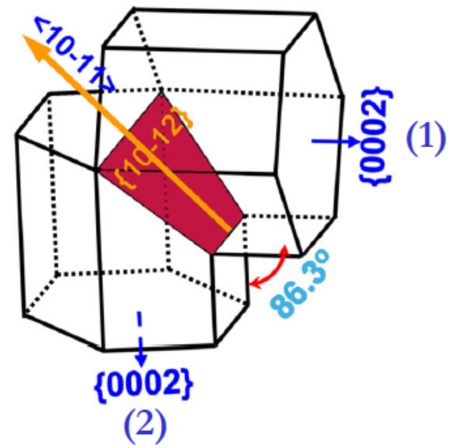


HCP crystal structure

Basic material properties:

Density	1.78 g/cm^3
Young‘s modulus	45 GPa
Shear modulus	17 Gpa
Poisson‘s ratio	0.35

- At room temperature Magnesium has only 2.5 active slip systems but to satisfy Taylor criterion 5 is needed.
- Twinning offers another independent deformation system under compression load, which has a limited strain accommodation capability and leads to tension-compression asymmetry.



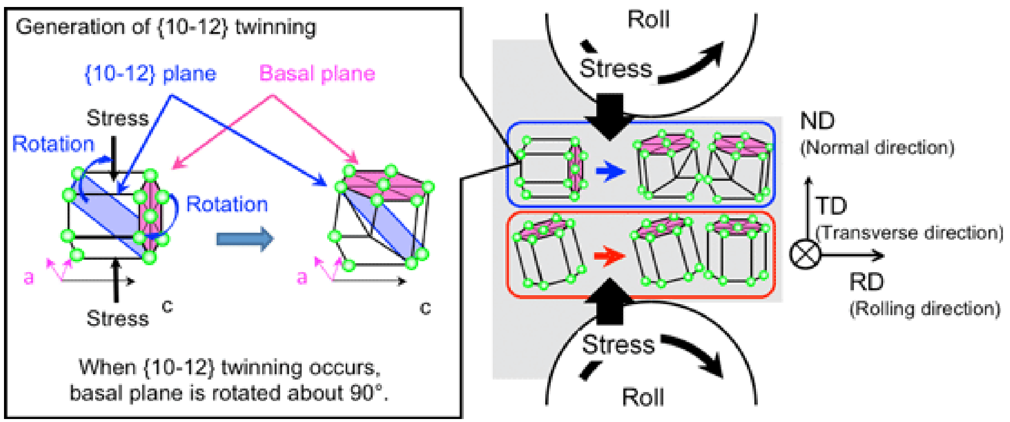
Twinning

(Source: Dariush Ghaffari Tari)

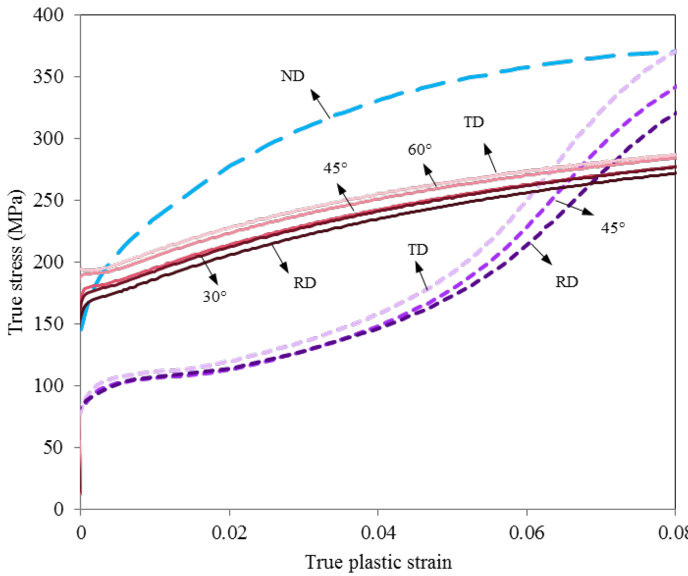
Introduction

AZ31B: Magnesium-Aluminium-Zinc Alloy

Norminal Composition wt.%								
Mg	Al	Zn	Mn	Ca	Cu	Fe	Ni	Si
Bal.	2.5-3.5	0.6-1.4	0.2-1.0	<0.04	<0.05	<0.005	<0.005	<0.05



(Source: www.aist.go.jp/aist_e/latest_research/2010/20100217/20100217.html)

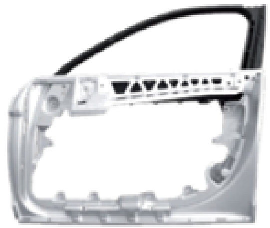


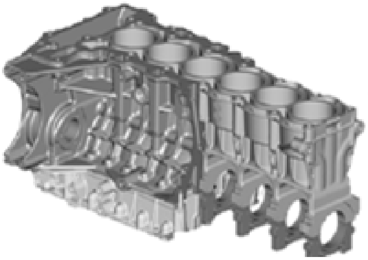
(Source: Dariush Ghaffari Tari)

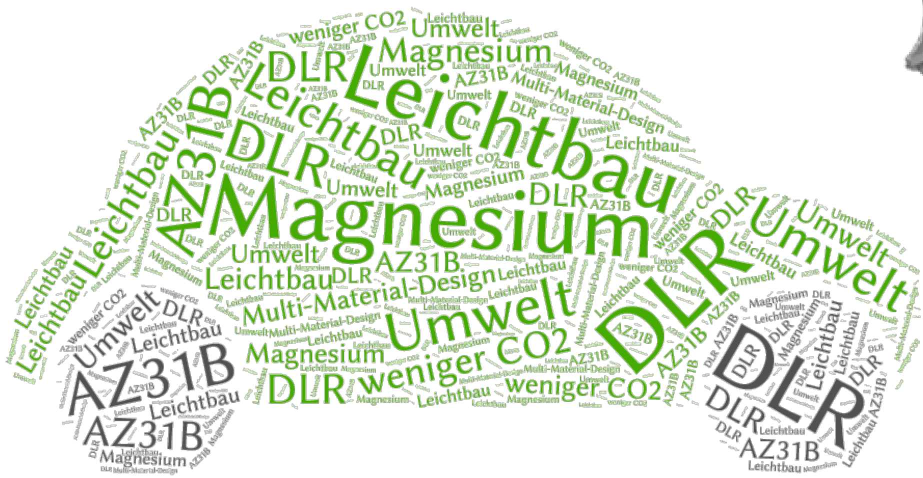
- Strong orientation **anisotropy** is formed during rolling and extrusion processes
- Strong **tension-compression asymmetry**
- **Poor ductility** at room temperature

Automotive application for magnesium

- Main application are casting parts
- Not used as main energy absorbing structures



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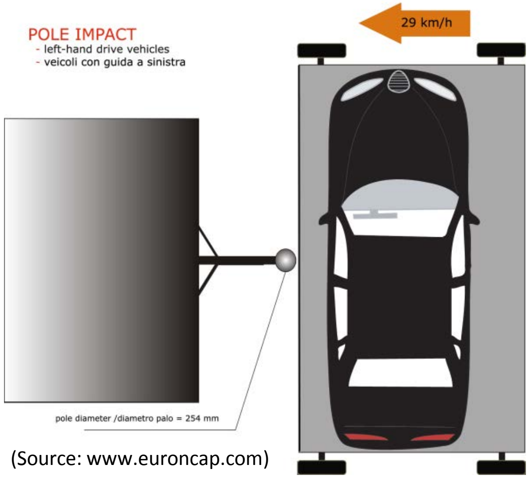
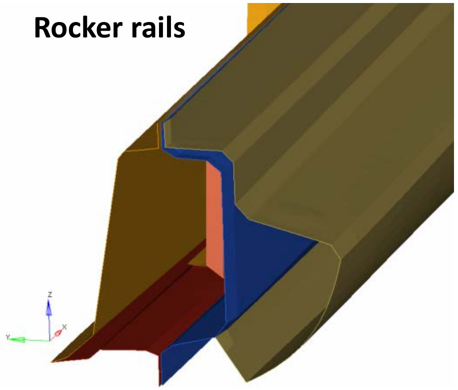
Motivation

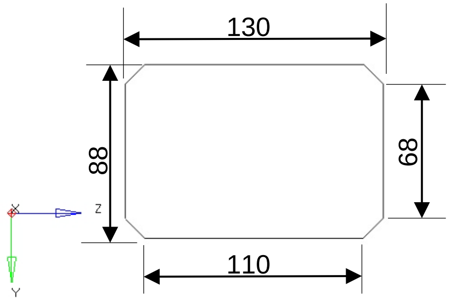


(Source: www.euroncap.com)

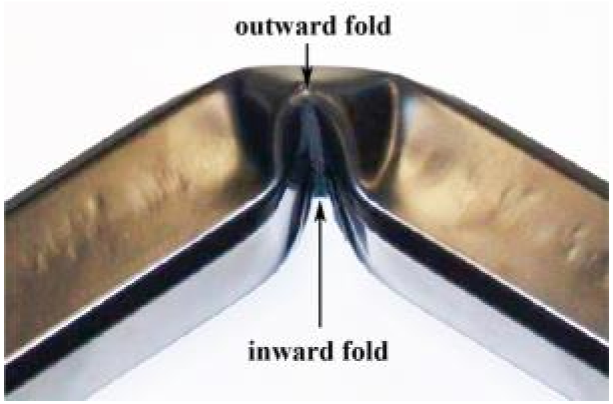


Source: Master thesis from M. Wongwatanyou

Simplified

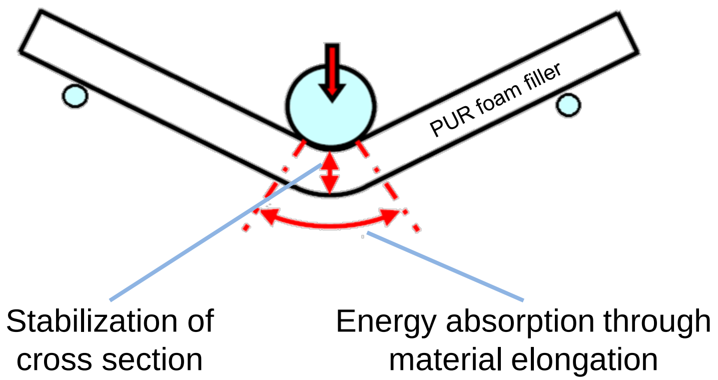


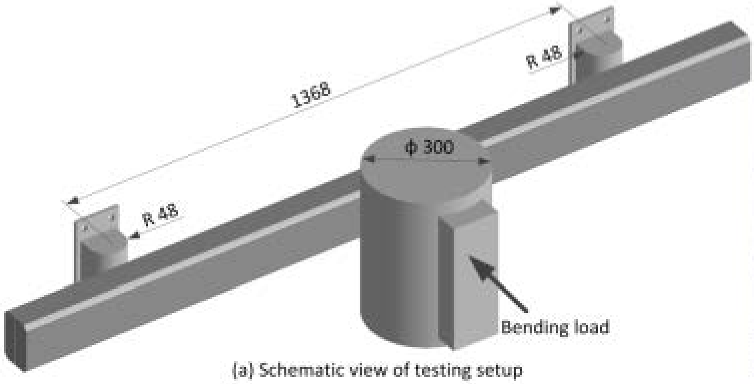
Basic profile



Foam 0.4 g/cm^3, 6.0 m/s

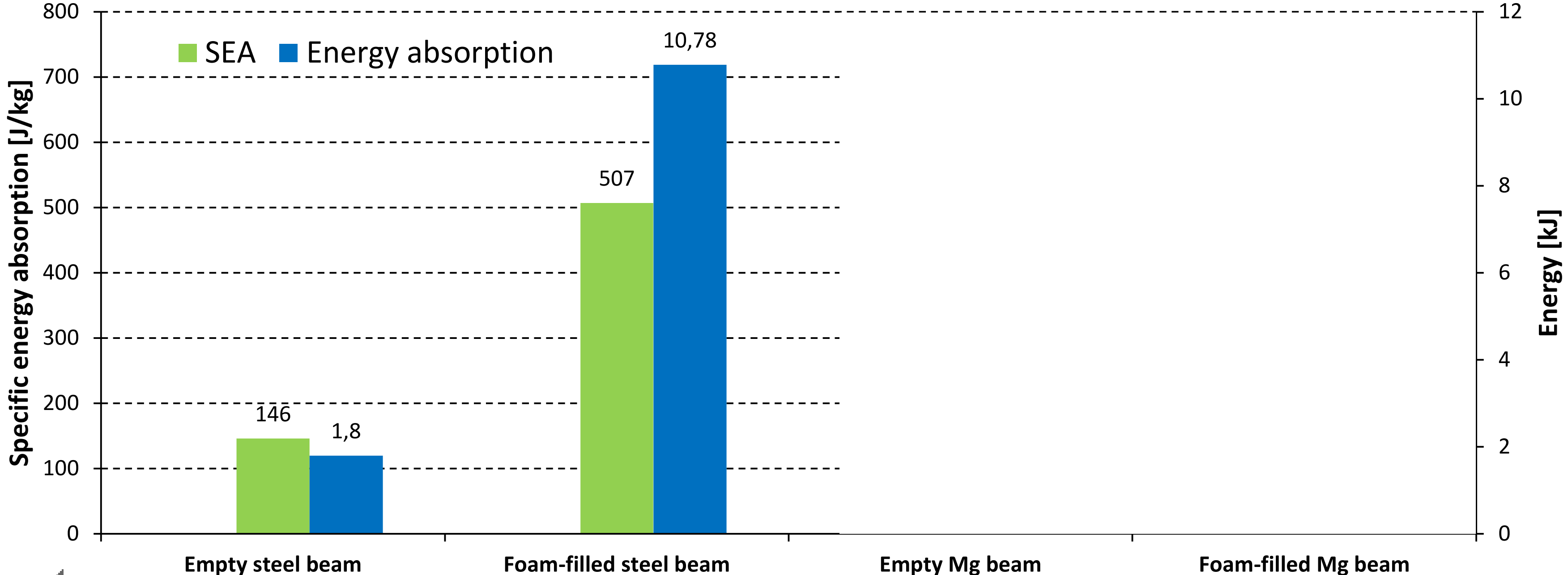
Motivation





(a) Schematic view of testing setup


(b) Testing system



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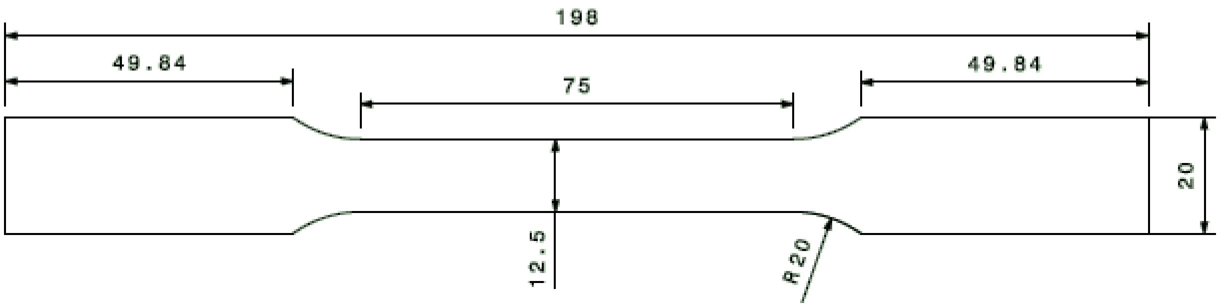
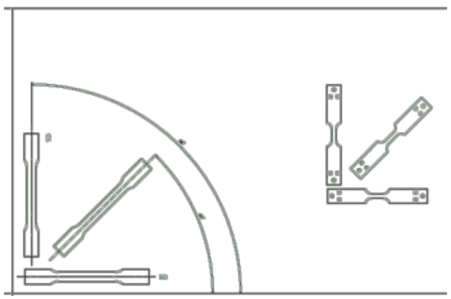
Material testing and characterization

- Q-S uniaxial tensile and compressive tests of Mg AZ31B

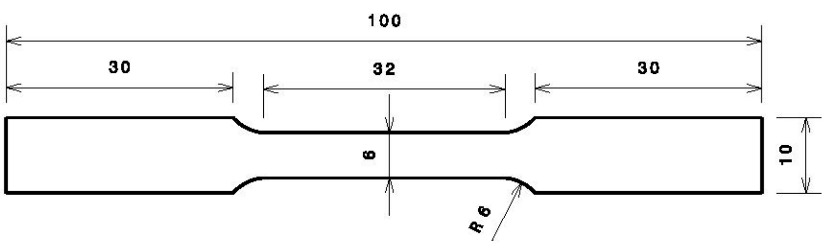


Full size specimen

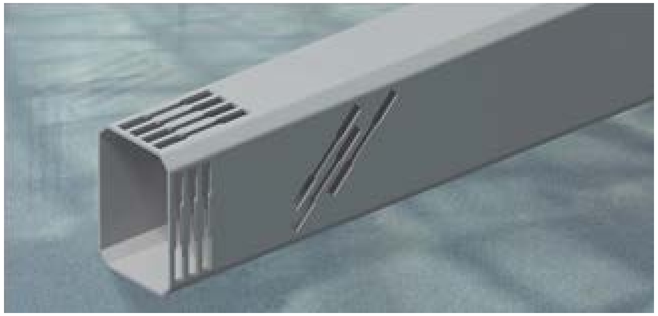


Anisotropy orientation

AZ31B-O Sheet



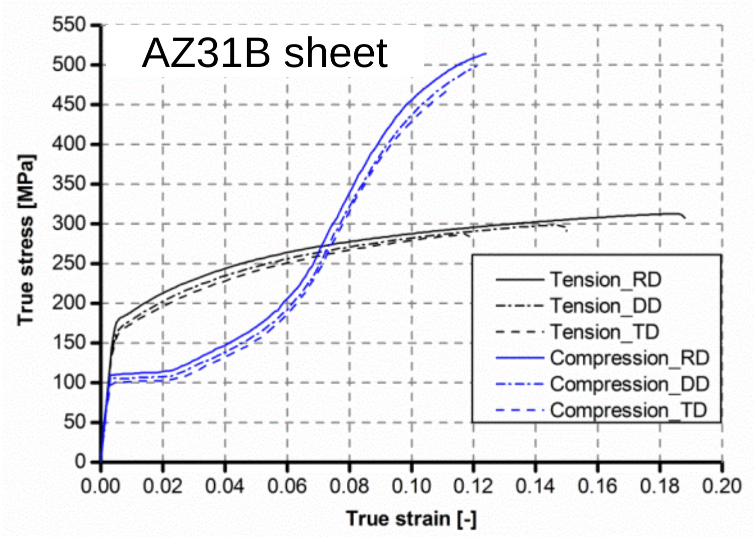
Sub-size specimen

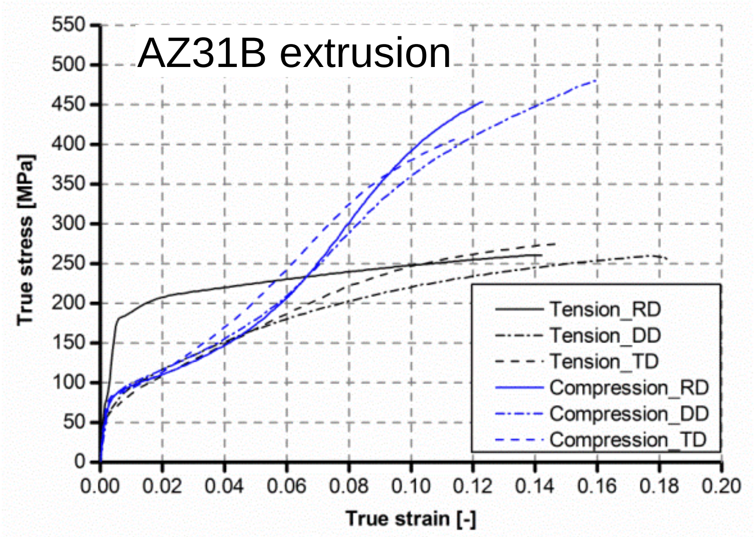


AZ31B-F extrusion

Material testing and characterization

❑ Q-S uniaxial tensile and compressive tests of Mg AZ31B





R **Results and discussion**

- AZ31B extrusion exhibits higher anisotropy of yield strength (≈120 MPa strength difference in tension) and total elongation (≈4% elongation difference in tension).
- AZ31B sheet exhibits lower anisotropy of yield strength in both tension and compression.
- Pronounced tension-compression asymmetry.
- Very high **strain hardening rate** under compression load
- AZ31B sheet is stronger but similarly ductile in both tension and compression.

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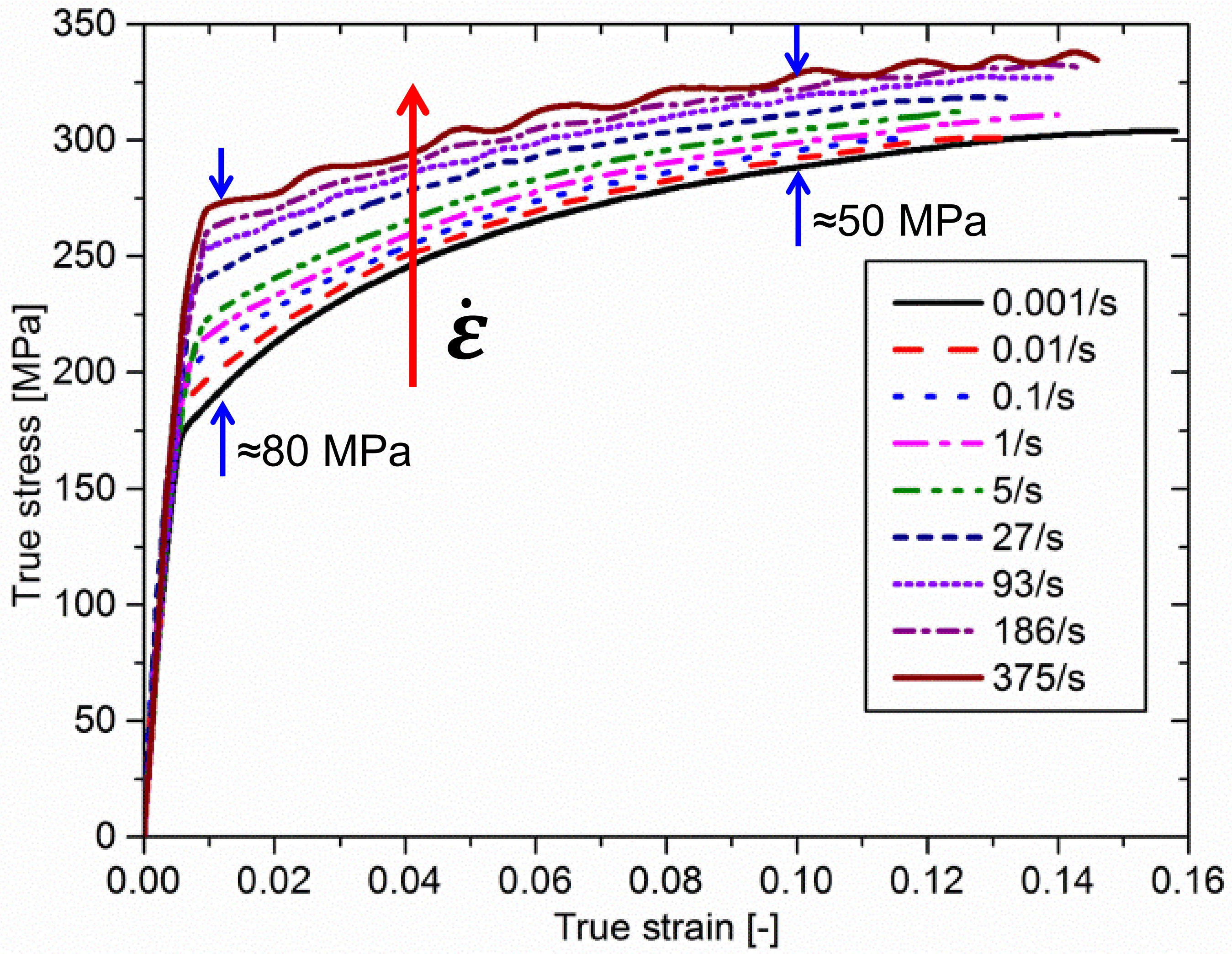
Material testing and characterization

- High speed uniaxial tensile tests



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Three-point bending: experiment

- Testing facility

DLR-FK quasi-static component crush platform

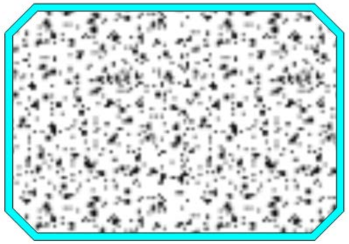
DLR-FK dynamic component crash platform

Three-point bending: experiment

❑ Design of experiment

Specimen	Shell material	Foam	Mass (kg)	Speed (m/s)
Empty and foam-filled steel beams				
SES	Steel DC04, T2.0	Empty	12.35	0.06
S20S	Steel DC04, T2.0	0.20 g/cm^3	16.92	0.06
S40S	Steel DC04, T2.0	0.40 g/cm^3	21.15	0.06
S40D	Steel DC04, T2.0	0.40 g/cm^3	21.15	6.0
Empty and foam-filled magnesium extruded beams				
XES	Mg AZ31B-F, T3.0	Empty	4.32	0.06
XED	Mg AZ31B-F, T3.0	Empty	4.32	2.0
X30S	Mg AZ31B-F, T3.0	0.30 g/cm^3	11.35	0.06
X30D	Mg AZ31B-F, T3.0	0.30 g/cm^3	11.35	4.5
Empty and foam-filled magnesium sheet beams				
MED	Mg AZ31B-O, T1.8	Empty	2.73	2.0
M05D	Mg AZ31B-O, T1.8	0.05 g/cm^3	3.75	2.0
M20D	Mg AZ31B-O, T1.8	0.20 g/cm^3	7.70	3.5
M30D	Mg AZ31B-O, T1.8	0.30 g/cm^3	9.58	3.5

Hollow profile



Fully foam-filled profile

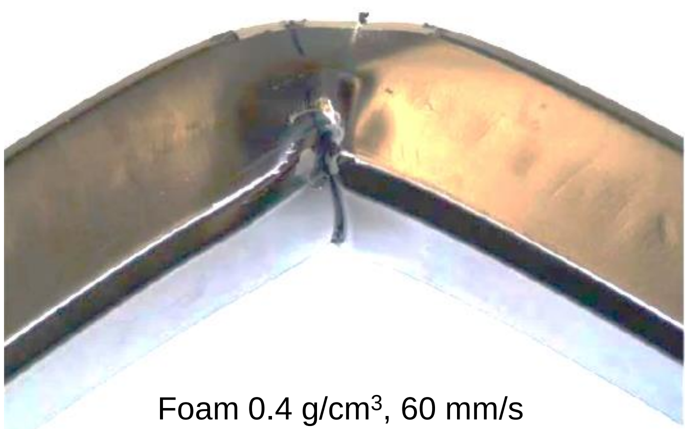
Polyurethane foam filling

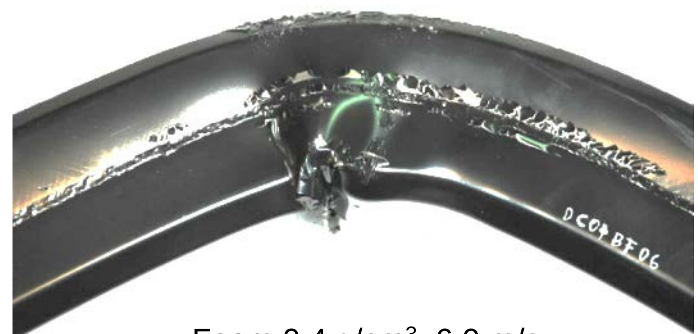
Three-point bending: experiment

- Deformation modes of steel beams


Empty, 60 mm/s

Foam 0.2 g/cm^3, 60 mm/s


Foam 0.4 g/cm^3, 60 mm/s

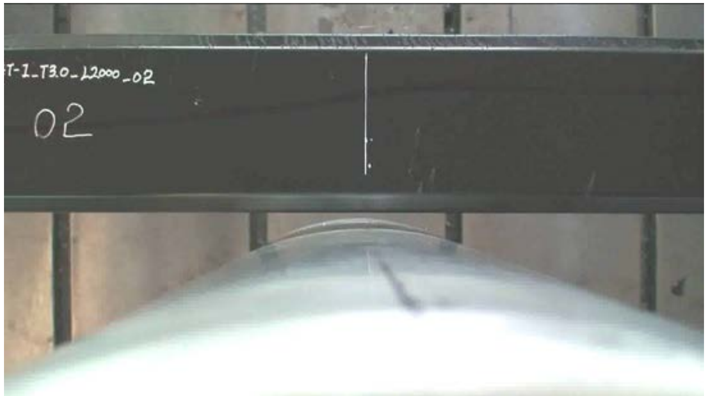


Foam 0.4 g/cm^3, 6.0 m/s

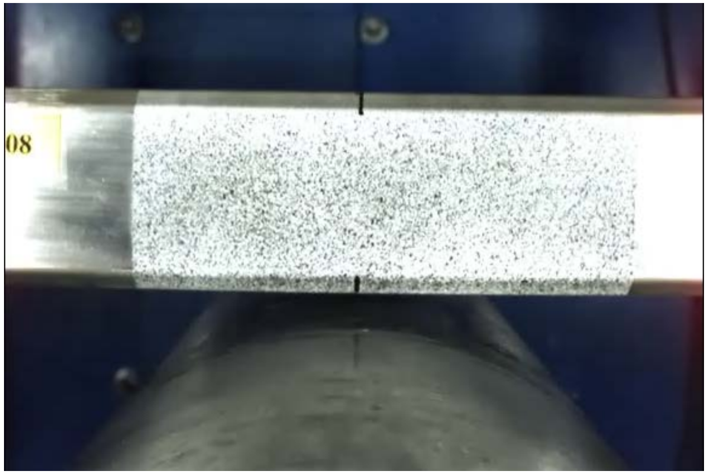
Three-point bending: experiment

- Deformation modes of Mg AZ31B **extruded** beams

Empty, 60 mm/s



Foam 0.3 g/cm^3, 60 mm/s

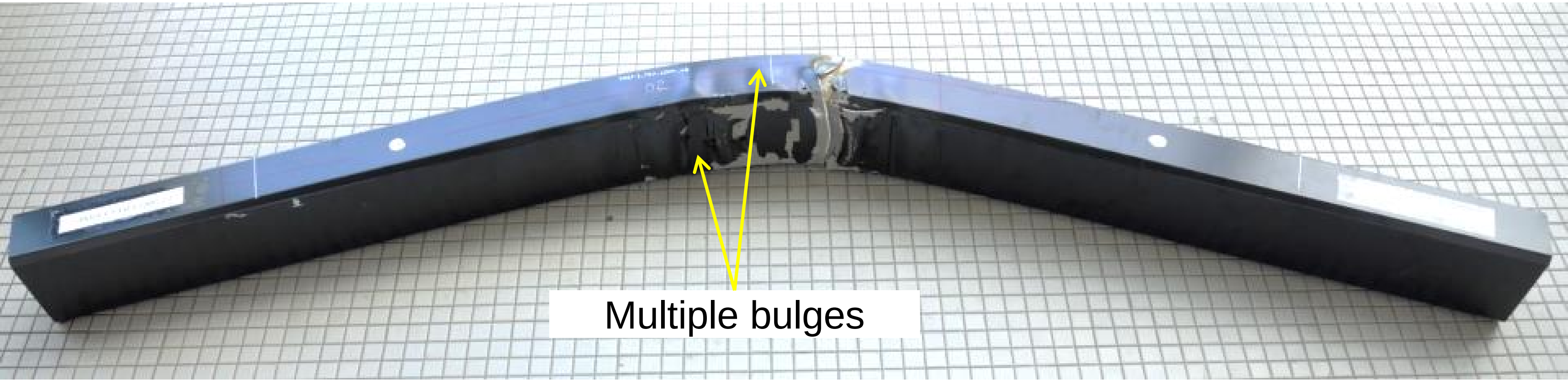


Empty, 2.0 m/s

Foam 0.3 g/cm^3, 4.5 m/s

Three-point bending: experiment

❑ Deformation modes of Mg AZ31B **extruded** beams



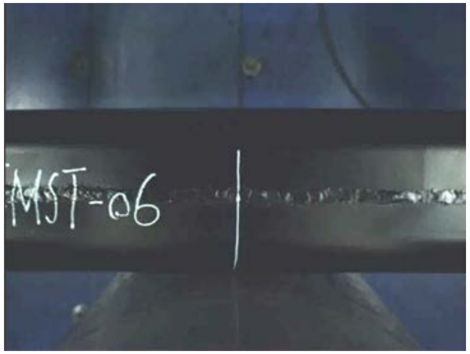
Three-point bending: experiment

- ❑ Deformation modes of Mg AZ31B **sheet** beams

Empty, 2.0 m/s

Foam 0.05 g/cm³, 2.0 m/s

Foam 0.2 g/cm³, 3.5 m/s



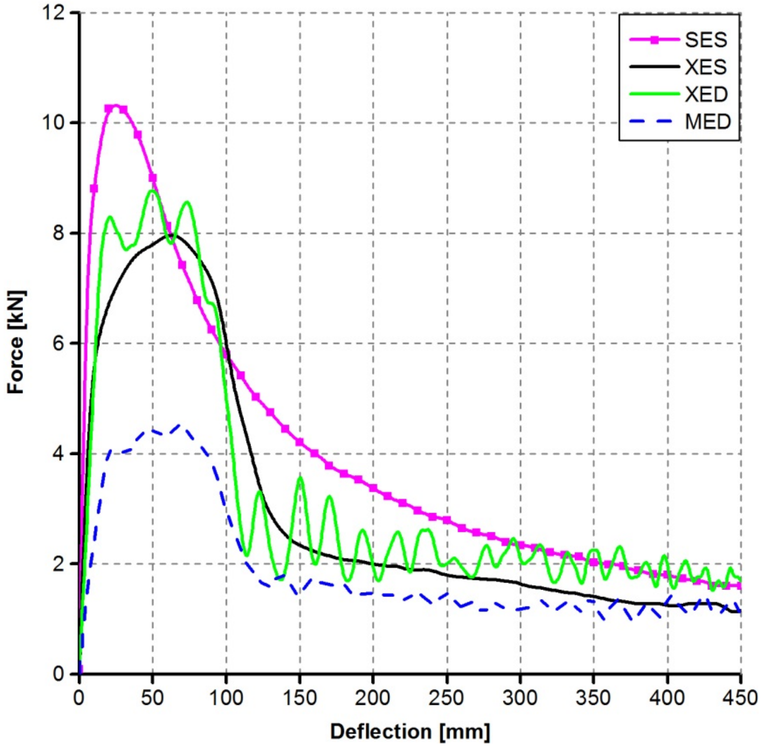
Foam 0.3 g/cm³, 3.5 m/s

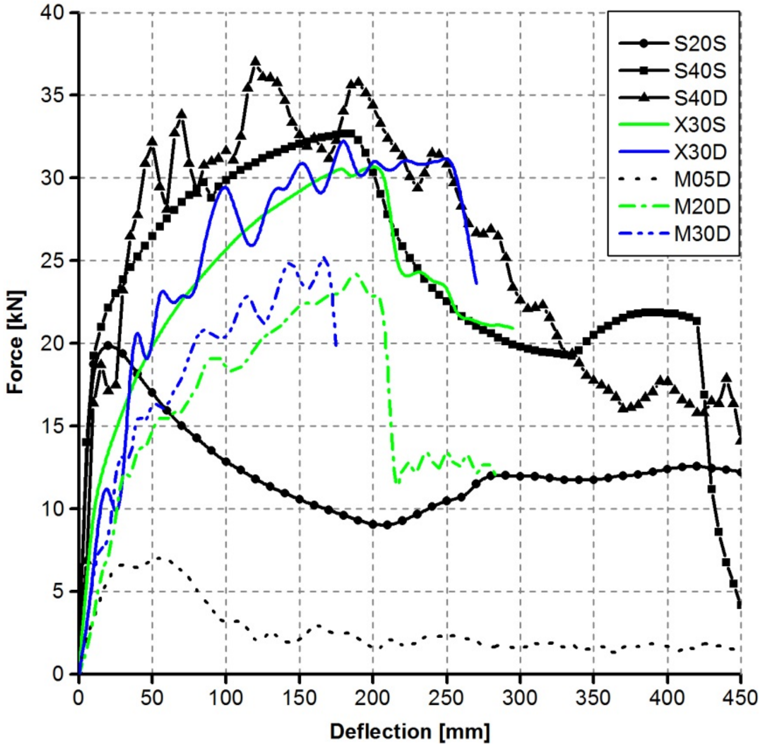
Three-point bending: experiment

- Deformation modes of Mg AZ31B **sheet** beams

Three-point bending: experiment

❑ Force-deflection curves

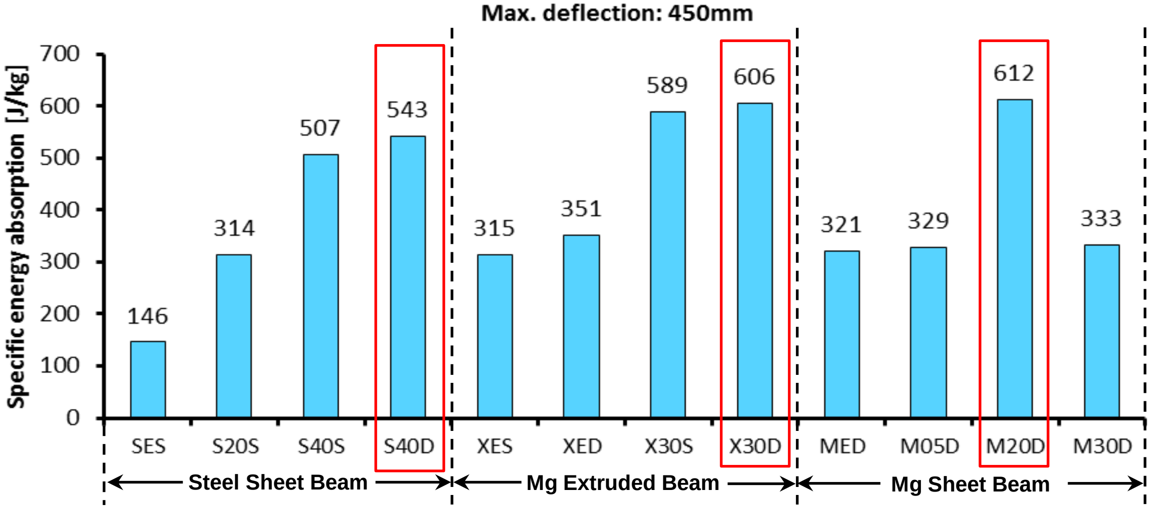




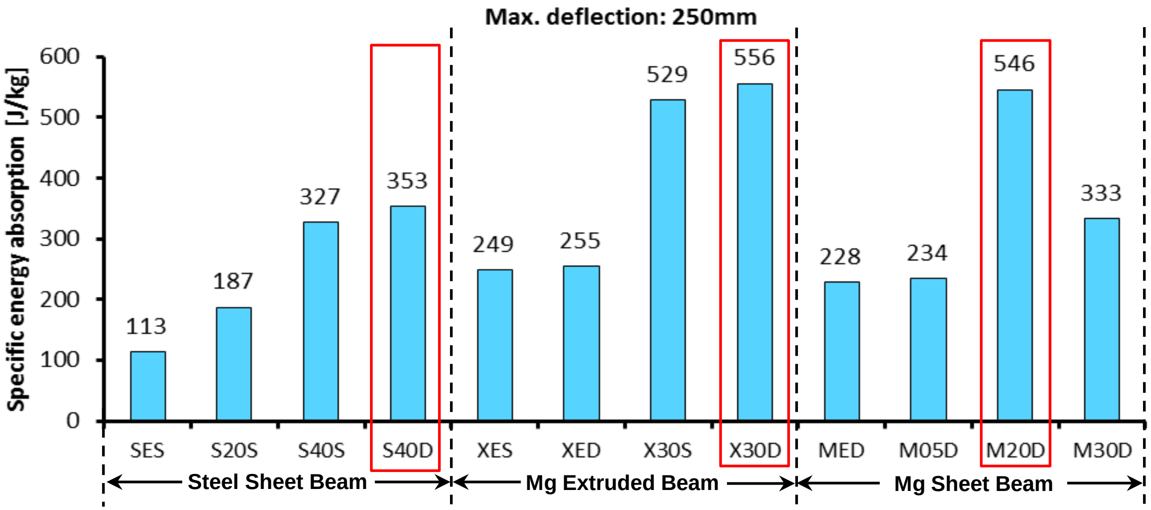
- Bending force of the beams was significantly increased through foam-filling. Higher foam density, higher bending force.
- Higher bending force under dynamic loads, but not significant for the foam-filled Mg AZ31B extruded beams (i.e. X30S vs X30D).
- Mg beams tended to fracture earlier compared with the steel beams due to the low ductility of magnesium alloys. Higher foam density, earlier fracture.

Three-point bending: experiment

❑ Specific energy absorption capacity



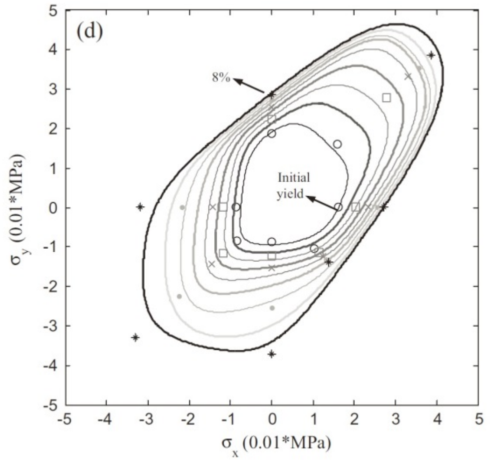
- The SEA of these beams except M05D and M30D was significantly improved through PUR foam filling.
- Mg AZ31B outperforms steel DC04 in terms of SEA for empty thin-walled beams under bending loads.
- The outperformance of Mg AZ31B is limited due to the premature fracturing.



- M20D vs S20S: M20D achieved nearly 2.9 times higher SEA than S20S, although M20D was 54% lighter than S20S and even 38% lighter than SES.
- Mg AZ31B may significantly outperform steel DC04 for foam-filled thin-walled beams for <u>limited deformation.</u>

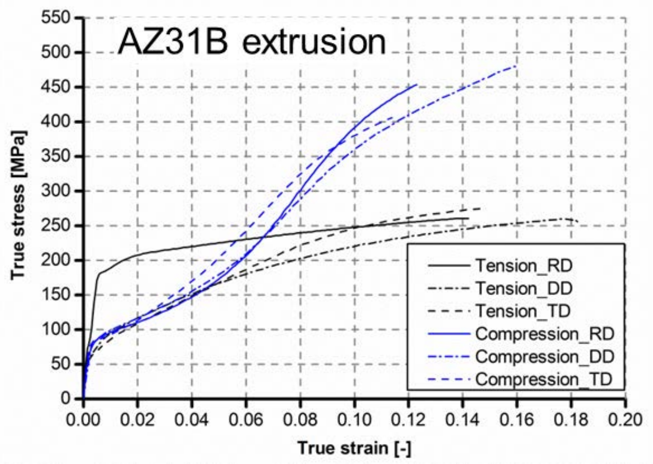
Three-point bending: simulation

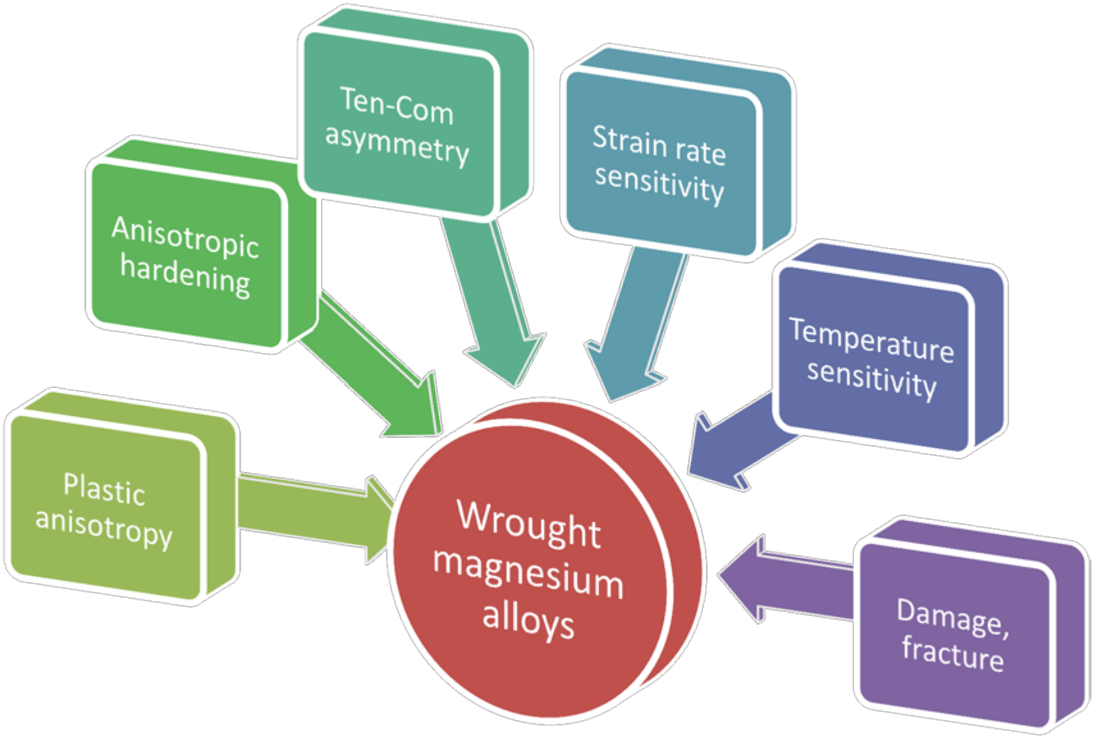
- Principle material properties of Mg AZ31B



Yield locus at different strain (test and fitting).

Source: D. Ghaffari Tari, M.J. Worswick, U. Ali, M.A. Gharghouri, Mechanical response of AZ31B magnesium alloy: Experimental characterization and material modeling considering proportional loading at room temperature, International Journal of Plasticity, 55 (2014) 247-267.





Three-point bending: simulation

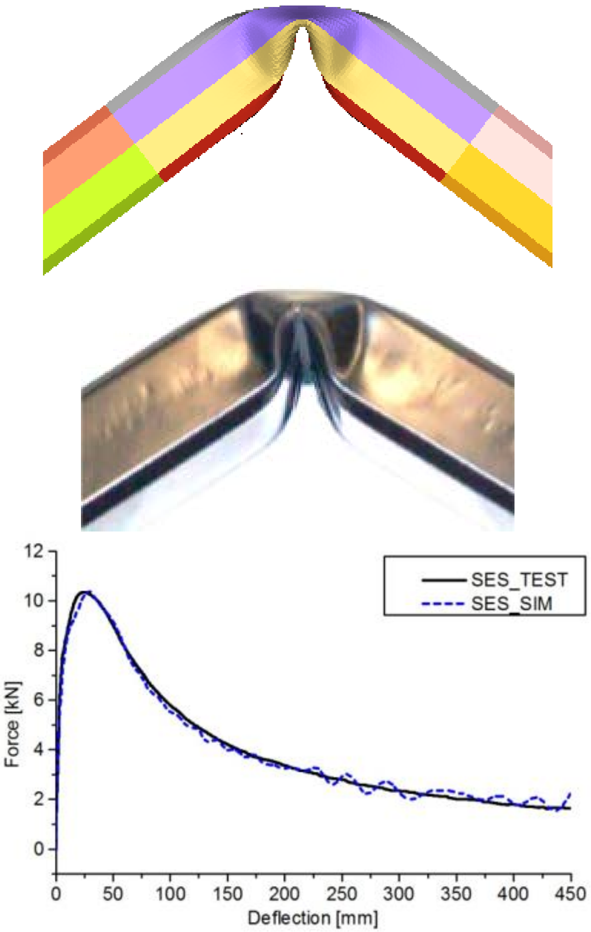
❑ Material models for metals in LS-DYNA

Model	Function	Plastic anisotropy	Hardening rule	Tension-compression asymmetry	Strain rate sensitivity
MAT_024	von Mises		Isotropic		✓
MAT_124	von Mises		Isotropic	✓	✓
MAT_103	Hill1948	✓	Isotropic + Kinematic		✓
MAT_242	Barlat-8P	✓	Isotropic + Kinematic		
MAT_233	Cazacu-Plunkett-Barlat (CPB2006)	✓	Isotropic	✓	
MAT_107	Johnson-Cook		Isotropic		✓
MAT_120	Gurson		Isotropic		✓

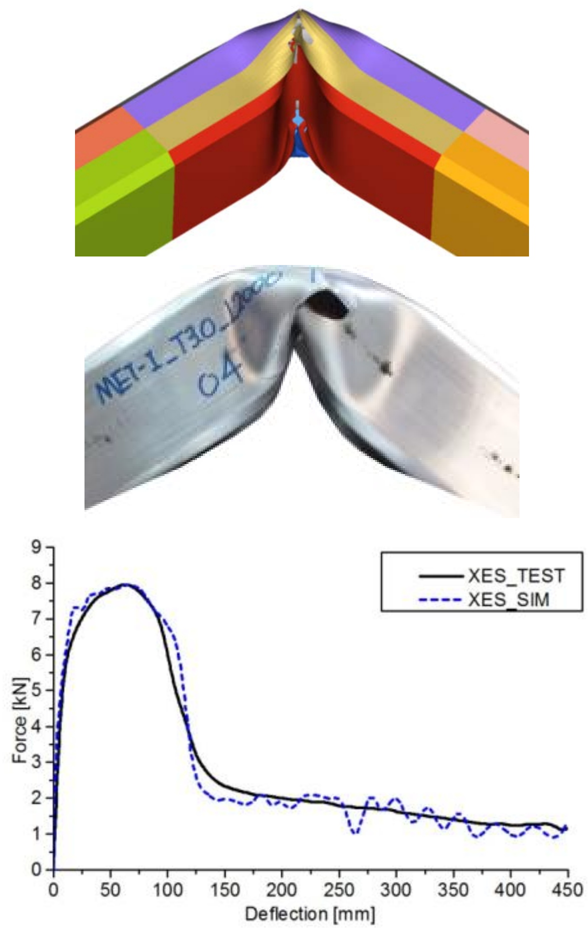
- **MAT_124** was adopted because tension-compression asymmetry is the predominant feature for magnesium alloy AZ31B.
- To consider fracture, we used the keyword ***MAT_EROSION** and failure criterion based on the max. principle strain.
- For the PUR foams, ***MAT_MODIFIED_CRUSHABLE_FOAM** was adopted.

Three-point bending: simulation

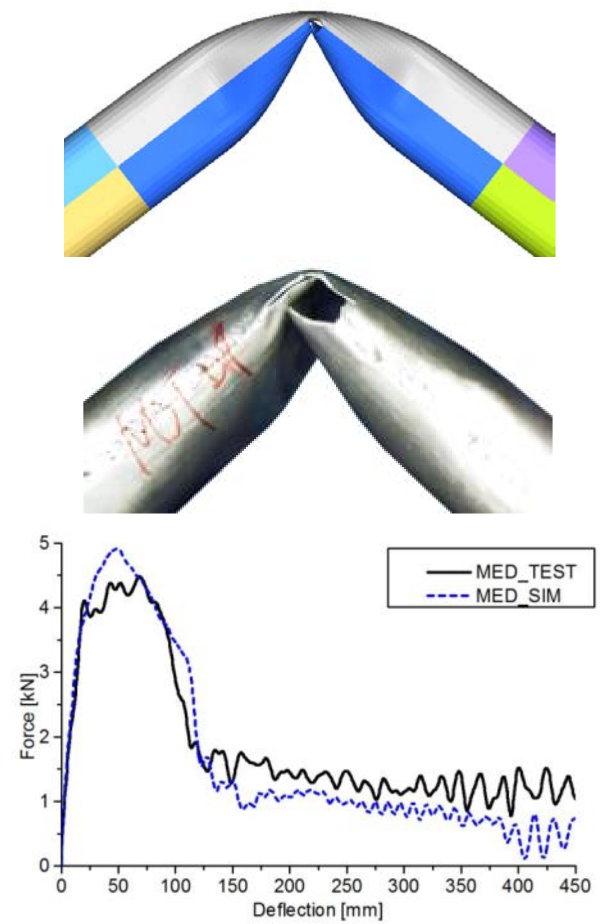
- FE simulation of empty beams using LS-DYNA



Very good correlation



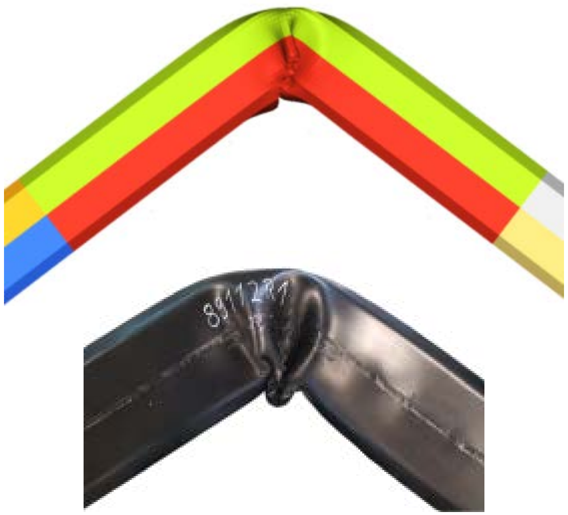
Very good correlation

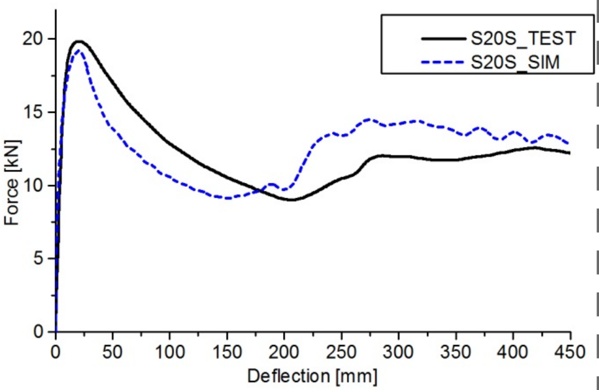


General good correlation

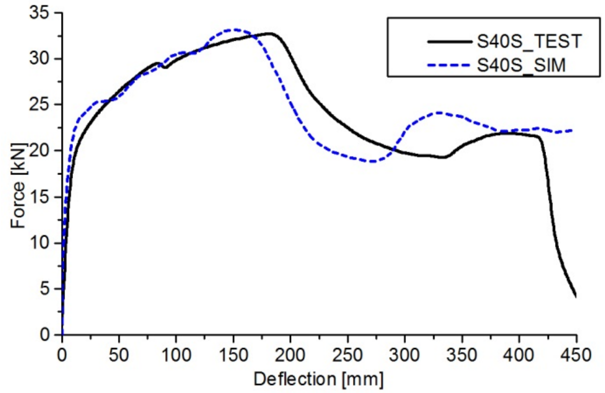
Three-point bending: simulation

- ❑ FE simulation of foam-filled beams using LS-DYNA

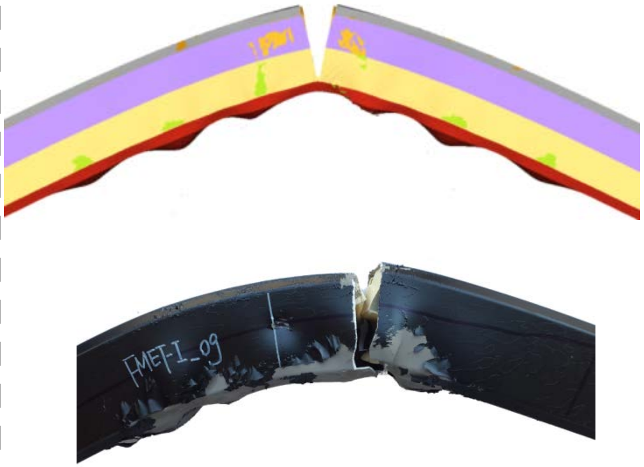


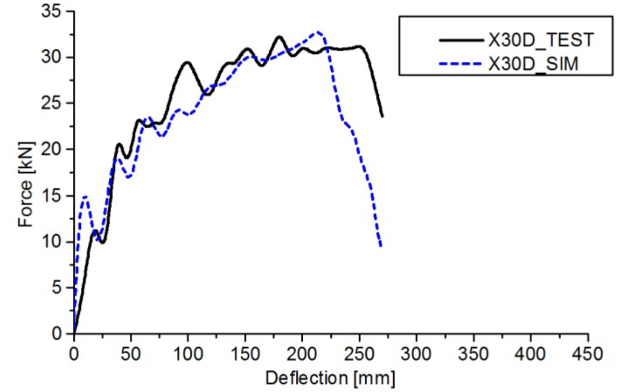


Very good correlation



Very good correlation

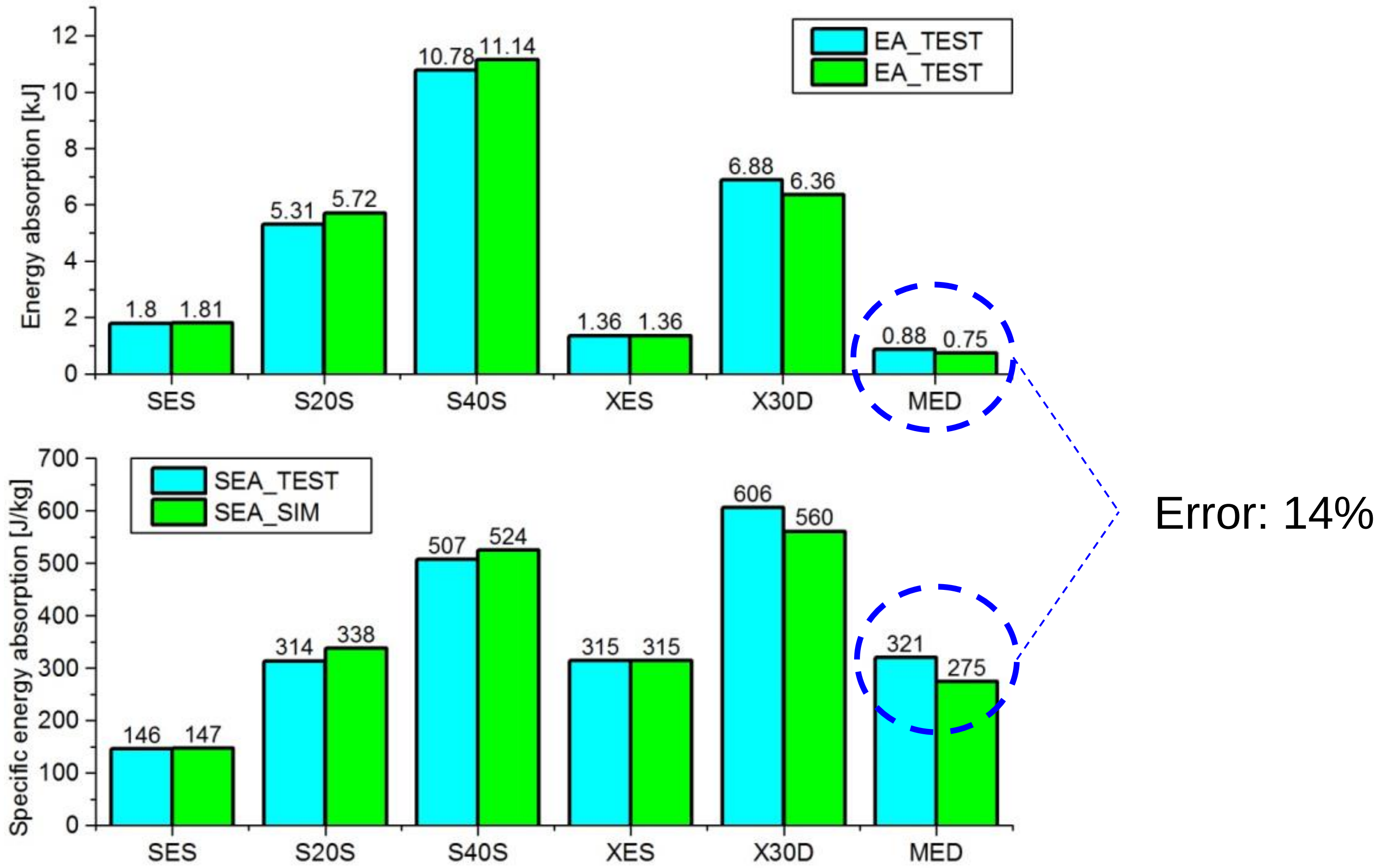




Very good correlation

Three-point bending: simulation

❑ Energy absorption capacity: Test vs Simulation



Max. correlation error is less than 14%

Conclusion

- Mg AZ31B extrusion and sheet exhibit significant anisotropy, strain rate sensitivity, tension-compression asymmetry and low ductility at room temperature
- Mg AZ31B outperforms steel DC04 in terms of SEA for empty thin-walled beams under bending loads
- But this outperformance of Mg AZ31B is limited due to the premature fracturing
- Mg AZ31B may significantly outperform steel DC04 for foam-filled thin-walled beams in the applications where only limited deformation is required
- Material model MAT_124 with calibrated material parameters may yield good simulation results (deformation patterns, force-deflection curves and energy absorption) for the magnesium beams subjected to bending loads

Thank you for your attention!